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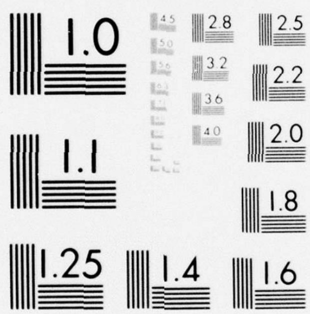

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Book 10
Bedrock Geologic Data

Seafarer Site Survey
Upper Michigan Region

for
U.S. Navy
Naval Electronic Systems Command
Washington, D.C.

by
EDAW inc.
under contract to
GTE Sylvania
Communication Systems Division

BOOK 10

BEDROCK GEOLOGIC DATA
of the
UPPER MICHIGAN REGION
PROJECT SEAFARER

for
U. S. Navy. Naval Electronic Systems Command

by
EDAW, Inc., 50 Green Street, San Francisco 94111

Under Contract to
GTE Sylvania, Communication Systems Division

April, 1976

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Seafarer Site Survey, Upper Michigan Region. Book 10. Bedrock Geologic Data.		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) 15 N00039-75-C-0309
9. PERFORMING ORGANIZATION NAME AND ADDRESS EDAW, Inc. 50 Green Street San Francisco, California 94111		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronic Systems Command Special Communications Project Office Washington, D. C. 20360	11	12. ~~REPORT DATE~~ Apr 1976
		13. ~~NUMBER OF PAGES~~ 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 36p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ELF Communications
Seafarer
Site Survey
Michigan
Environmental Data
Bedrock Geology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Most of the rocks within the Study Area are of Precambrian Age (more than 600 million years old). Since at least the mid-Paleozoic time, the area has been tectonically stable. Hard bare rock is exposed at the surface in relatively small areas, but a soil and glacial mantle ranging from a few to a few hundred feet thick overlies the bedrock throughout most of the area.

A Bedrock Geologic Data Map has been compiled which gives the areal distribution of bedrock in the Study Area.

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SUMMARY

Bedrock geology refers to the areal distribution, thickness, sequence, and types of indurated rocks that make up the earth's crust. Within the Study Area, most of the rocks are of Precambrian age (more than 600 million years old). These ancient rocks have been divided into the Archean Series, the Huronian Series, and the Keweenawan Series. The Archean rocks are the oldest group, and they consist principally of altered lava flows intruded by granite, with associated masses of granitic gneiss. The next younger rock series, the Huronian, is largely a thick section of sedimentary rocks that overlaps the Archean Series. These sedimentary units, mainly graywackes and dolomites, have been intruded by basic igneous rocks. Metamorphic rocks, mainly slates and quartzites, occur elsewhere in the Huronian section. The Huronian sedimentary section also contains several iron-rich units known as "iron formations". The youngest Precambrian rocks, the Keweenawan Series which are found west of the Study Area, are principally lava flows and conglomerates, although minor units of shale and sandstone exist.

Shallow-dipping Paleozoic sedimentary rocks overlie the Precambrian sequence and crop out in the eastern part of the Study Area. Here Cambrian and Ordovician sedimentary formations dip gently in a southeasterly direction to form the northwesterly rim of the Michigan Basin. These rocks are mainly sandstones, dolomites, shales, and limestones. Younger (Mesozoic and Cenozoic) rocks have been almsot entirely removed by glaciation. The areal distribution of bedrock in the Study Area is shown on the Bedrock Geologic Data Map.

The Lower and Middle Precambrian rocks were affected by major episodes of mountain building during Precambrian time involving folding, thrust faulting, and metamorphic alteration. Since at least the mid-Paleozoic (about 350 million years ago) the Study Area has been tectonically stable, with Pleistocene glaciation being the major factor in modification of the landscape. Hard bare rock is exposed at the surface in many relatively small areas, but a soil and glacial mantle ranging from a few to a few hundred feet thick overlies the bedrock throughout most of the Study Area.

The Bedrock Geologic Data Map was prepared by compiling available published and unpublished geologic data and maps adjusted to a common scale. The relationship of this map

to the Surficial Geologic Data Map and the Soils Data Map should be kept in mind during its use. The Bedrock Geologic Data Map provides useful data on the type of rock underlying a specific area, and descriptions of the various rock units are contained in this narrative. The map gives only an indication of the rock types present at depth and does not consider the thickness of the overlying deposits.

Therefore, the Surficial Geologic Data Map and the Bedrock Geologic Data Map should be used in conjunction with each other to determine the maximum amount of information about geologic conditions in a given area. For instance, by overlaying and comparing these maps and utilizing the data on rock descriptions contained in this narrative, it is possible to determine where rock outcrops occur and the type of rock present.

EVOLUTION

Processes and Time Leading to the Existing Conditions

The geologic history of the Study Area has been reconstructed from the record contained in the various rocks exposed there. The record represents a long period in the earth's history, stretching over billions of years from early in the Precambrian Era to the present, and documents many episodes of shallow water deposition, mountain building, and erosion of the land surface. Because many of the rocks which once covered the Study Area have been removed by erosion or complexly deformed, it is an incomplete record.

The Precambrian Era (which lasted from about 4.7 billion years ago to 600 million years ago) is especially difficult to reconstruct because of the highly deformed rocks which represent this extremely long and ancient period in the earth's history, during which several cycles of deposition, metamorphism and igneous intrusion took place. However, a generalized history has been developed which gives the highlights of the Study Area's geologic evolution.

The oldest known Early Precambrian (Archean) rocks in the Study Area are schists, greenstone, and quartzite (the metamorphosed equivalents of basaltic lavas and sandstone). The presence of these rocks indicates a history of sedimentation and volcanic activity (in part subaqueous) followed by episodes of metamorphism.

An early episode of crustal disturbance was the Laurentian Orogeny, during which time the previously formed layered rocks were folded, altered and locally intruded by granitic magmas. These granitic bodies were later metamorphosed to become gneisses and gneissic granite. This relatively minor orogenic episode took place about 2.6 billion years ago, and culminated in local uplift and erosion.

A period of crustal subsidence followed, during which conglomerates, sands, and explosively ejected volcanic materials were deposited in shallow seas. The Algoman Orogeny, a period of high-grade regional metamorphism caused by widespread and intense crustal deformation, followed the formation of these layered rocks. Folding, faulting, granitic intrusion, altering of pre-existing rocks, uplift, and mountain building marked the Algoman and the end of the Early Precambrian in the Study Area at about 2.4 billion years ago.

Over the eroded surface of the Archean rocks, Middle Precambrian (Huronian) seas repeatedly transgressed and regressed to form a sequence of conglomerates, sandstones, algal dolomites, iron formations (iron mineral-rich cherts), and shales. Felsitic and basaltic volcanic rocks were introduced into the sequence by near surface volcanic activity. These rocks have since been metamorphosed in part to slate, quartzite, and graywacke. Evidence has also been found in the Menominee region of glaciation during the early part of the Huronian. The Huronian Period ended about 1.7 billion years ago with renewed major crustal deformation (termed the Penokean Orogeny). Although not as intense as the Algoman, it was also characterized by folding, faulting, igneous intrusion of dikes and sills, regional metamorphism, uplift, and mountain building.

The latest period in the Precambrian Era was the Keweenawan, which lasted from about 1.7 billion years ago until about 600 million years ago. During this time, great extrusions of basaltic lava poured out of fissures in the earth and flowed over an eroded surface developed on the pre-existing sedimentary, metamorphic, and intrusive rocks. Apparently, the lava entered the ancient Lake Superior Syncline, which sagged to accept the deposits. The many thousands of feet of volcanic flows which accumulated became the host for almost all of the native copper deposits of the Northern Peninsula. In addition, gabbro and small amounts of granite were emplaced into the flows. Interbedded with some of the lavas are coarse sediments, primarily conglomerate and sandstone, which were probably deposited by streams flowing down from highland areas and across the flows. The subsiding Lake Superior Syncline was the site for the subsequent deposition of many thousands of feet of sediments. A period of gentle uplift and erosion of some of these sedimentary rocks ended the Precambrian Era.

During the early Paleozoic Era between about 600 and 400 million years ago, the Study Area was again submerged, and the present sequence of gently dipping sedimentary rocks which overlie the Precambrian rocks were deposited. Renewed deposition began early in the Cambrian Period, as streams flowed from highland areas to what may have been a freshwater basin. Tilting of these Early Cambrian sediments preceded the advance of Upper Cambrian and Ordovician seas, in which were deposited sandstone, conglomerate, shale, and dolomite. The gently dipping sedimentary rocks which resulted from these periods of deposition vary in thickness, since they were laid down on an irregular erosional surface.

Since the mid-Paleozoic, the Study Area has been an extremely stable portion of the earth's crust. Until the Pleistocene Epoch and the invasion of glaciers from the north, the only major geologic processes which affected the area were wind and water erosion. While neighboring areas were sites of sedimentation during most of the Paleozoic, the land surface of the Study Area apparently was mainly above sea level, although generally topographically low.

The action of glacial ice, especially during the latest Ice Age (the Wisconsin stage), profoundly altered the landscape of the Study Area. Deposition of the glacial deposits (which mantle most of the Study Area and are up to 300 feet thick in some areas) consisting of end and ground moraines, outwash plains, and lake sediments, has probably been the most important factor in determining the present topography (see the Evolution section in the Surficial Geologic Data Report for a discussion of the glacial history of the area).

Anticipated Future Conditions

The Study Area is presently geologically stable, with no significant tectonic, volcanic, or seismic activity occurring. Although the geologic processes of weathering, erosion, and stream deposition continue, these processes are occurring at such a slow rate that it is unlikely they will alter the present landscape significantly within the next several centuries. Man's activities appear to be the only significant factor that could alter the landscape within the foreseeable future.

DISTINCTIVE UNITS AND CHARACTERISTICS

Introduction

The oldest rocks exposed in the Study Area are the Lower Precambrian (Archean) metamorphic rocks, which consist mainly of schist, greenstone, and quartzite with associated intrusive granite and gneiss. The Middle Precambrian (Huronian) rocks include a thick sequence of sedimentary and volcanic rocks which have been metamorphosed to schists, slates, quartzites, iron formations, and greenstone. Both the Lower and Middle Precambrian rocks have been subjected to several episodes of folding, faulting, igneous intrusion, metamorphism and erosion.

The Upper Precambrian (Keweenawan) sequence found north and west of the Study Area was deposited after these episodes of intense deformation. These rocks consist of unmetamorphosed basaltic lavas and sedimentary rocks, including shales, sandstones, and conglomerates. Another period of deformation followed, which resulted in tilting, and the erosion of any Upper Precambrian rocks that may have existed in the Study Area.

In places, the Precambrian rocks are overlain by gently dipping sandstones and dolomites of Cambrian and Ordovician Age. These Paleozoic rocks are the youngest bedrock units in the Study Area. Any rocks younger than these that may have existed were removed by glacial erosion during the Pleistocene Ice Ages, and thick deposits of unconsolidated glacial debris cover the bedrock throughout much of the area (see Surficial Geologic Data narrative).

Within the Study Area, several episodes of folding, metamorphism, and erosion have considerably altered the older Precambrian rocks, and definite correlations cannot be made, in most cases, between similar rock types exposed in different parts of the Study Area. Consequently, the Lower and Middle Precambrian rock units are described under separate headings relating to their geographic locations: the Marquette Range, the Iron River-Crystal Falls-Menominee Area, and Widespread Areas of Uncertain Correlations (see Key to Map Interpretation, Figure 1).

The Paleozoic rocks are generally continuous and readily traceable units, however, and correlations between exposures from one area to another can be made. Consequently, similar rock types in different areas have been identified and mapped as the same formation, and descriptions of these rock units apply to all portions of the Study Area.

FIGURE 1. KEY TO MAP INTERPRETATION

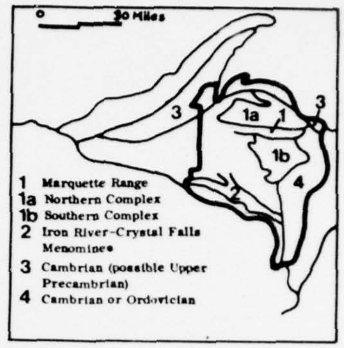
PALEOZOIC

ORDOVICIAN

Obr	Black River
Oat	Au Train Formation
O€sd	Undifferentiated

CAMBRIAN

€m	Munising Formation
€j	Jacobsville Sandstone
€ls	Undifferentiated



Marquette Range - "Northern Complex" - "Southern Complex" Area		Iron River - Crystal Falls - Menominee Area		Correlation with other Precambrian units uncertain.	
MIDDLE PRECAMBRIAN					
		sfs	Stambaugh and Fortune Lakes Slates		
		gkh	Hiawatha Graywacke	dh_2	Diabase
		ir	Riverton Iron Formation	stn	Siltstone
		sd	Dunn Creek Slates	ms	Magnetic strata, mostly concealed by overburden
		gba	Badwater Greenstone		
				i_2	Iron formation
gkm	Michigamme Graywacke	gkm	Michigamme Graywacke		
				s_2	Slate
		fh	Hemlock felsic volcanics		
				gk_2	Graywacke
ib	Bijiki Iron Formation				
				d_2	Dolomite
pc	Clarksburg mafic pyroclastics	gh	Hemlock Greenstone		
				q_2	Quartzite
ig	Greenwood Iron Formation				
				ak_2	Arkose
sm	Michigamme Slate				
qg	Goodrich Quartzite	qg	Goodrich Quartzite		
				c_2	Conglomerate
in	Negaunee Iron Formation	iv	Vulcan Iron Formation		
ss	Siamo Slate				
				tr	Tillite
qa	Ajibik Quartzite	qf	Felch Formation (quartzite)		
				r	Rhyolite
sw	Wewe Slate				
				mtf_2	Mafic tuff
dk	Kona Dolomite	dr	Randville Dolomite		
				mag_2	Mafic agglomerate
qm	Mesnard Quartzite	qs	Sturgeon Quartzite		
ce	Enchantment Lake Formation (conglomerate)	cf	Fern Creek Formation (conglomerate)		
LOWER PRECAMBRIAN					
gr	Granite	gr	Granite	mig	Migmatite
gn	Granitic to dioritic gneiss	gn	Granitic to dioritic gneiss	i_1	Iron formation
sy	Syenite	hs	Metasediments of Solberg Schist and Six Mile Lake Amphibolite	mtf_1	Mafic tuff
				g_1	Basaltic greenstone
gd	Granodiorite	ake	East Branch Arkose	g_1/mtf_1	Basaltic greenstone and mafic tuff
di	Diorite	gq	Quinnesec Greenstone		
h	Hornblende schist and amphibolite				
gb	Gabbro				
db	Diabase				
u	Ultramafic rocks				
fak	Felsic agglomerate of Kitchi Schist				
fm	Felsic porphyry of Mona Schist				
ftm	Felsic tuff of Mona Schist				
mtm	Mafic tuff of Mona Schist				
gm	Basaltic greenstone of Mona Schist				

There are 71 formations and units shown on the Bedrock Geologic Data Map, of which 65 are assigned to the Precambrian Era. Each has been mapped according to its predominant lithology, and other rock types may be included. Since the precise ages of Precambrian rocks are very difficult to determine, relative ages have been assigned only to units designated with a formal name (such as Michigamme Graywacke). They are described in chronological order, beginning with the oldest. Rock units which carry only a lithologic designation (such as granodiorite) are placed in the chronologic sequence where it is believed they belong, but their relative ages have not been determined.

The mapping units were combined into four groups (each of which is represented by a separate color on the Bedrock Geologic Data Map) on the basis of rock type and age. The older, harder, Middle and Lower Precambrian rocks are divided into Gneiss, Other Metamorphic Rocks (including quartzite, slate, greenstone, schist, and other lithologies), and Igneous Rocks (predominantly granite). The relatively softer Paleozoic sedimentary rocks make up the remaining unit.

Geologic Units

Older Metamorphic Rocks

- <u>Marquette Range</u>

  a. Lower Precambrian (Archean)

gm, mtm,
ftm, fm-- <u>Mona Schist</u>. The Mona Schist is the oldest formation in the Study Area and contains four separate units, all of which are found primarily in the Marquette area. The units are greenish in color, massive to schistose, and volcanic in origin. The estimated minimum total thickness of the formation ranges from 13,000 to 21,000 feet. (Gair and Thaden, 1968, pp. 6-18.)

<u>gm - Basaltic Greenstone</u>. The Basaltic Greenstone unit of the Mona Schist Formation consists of very fine grained, dull green to brownish green, massive to schistose metamorphosed basalt. Many ellipsoidal structures may indicate deposition, at least in part, under water. This greenstone is in some places interlayered with amphibole schist of the overlying Mafic Tuff Unit.

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Washington, D.C.

6 Mile Square

Scale 0 1 2 4 6 miles

North

BEDROCK GEOLOGY

- Geologic Formation (See Text)
- Geologic Contact
- Approximately Located Geologic Contact
- Inferred Geologic Contact

PALEOZOIC ERA

- Cambrian Ordovician System

LOWER & MIDDLE PRECAMBRIAN ERA

- Gneiss
- Other Metamorphic Rocks
- Igneous Rocks
- Inactive Fault
- Approximately Located Inactive Fault
- Keweenawan Dikes

MARQUETTE
NEGAUNEE
ISHPEMING
IRON RIVER
IRON MOUNTAIN
NORWAY
KINGSFORD
46°30'
46°15'
46°00'
45°45'
45°30'

mtm - Mafic Tuff. The Mafic Tuff Unit is generally fine grained, dark green to deep brown to pale gray-green amphibole schist. It is chemically similar to basalt, and probably resulted from the metamorphism of mafic volcanic ash beds. Typical of the unit are lensoid shaped layers, usually several inches thick and 10 to 30' long, which weather and break away in slabs.

ftm - Felsic Tuff. The Felsic Tuff Unit consists primarily of chloritic schist and slate, which are dull shades of green or brownish green, and which vary in fissility from schistose to slaty. The rock varies in composition, but is generally chlorite and quartz-rich and probably has a mixed volcanic and sedimentary origin. Small hematite-rich shear zones in the slaty part of the unit have been prospected.

fm - Felsic Porphyry. The Felsic Porphyry Unit is composed of a variety of gray to brownish gray quartz-rich felsitic slates and schists. The main types include fissile to flinty, fine grained. Commonly porphyritic, quartz and sericite-rich rocks, and massive to schistose, medium grained, quartz-feldspar rocks. The rocks occur as thin, conformable, intrusive or volcanic bodies, as well as tabular, crosscutting, intrusive dikes.

fak-- Felsic Agglomerate of Kitchi Schist. This felsic unit of the otherwise dominantly mafic Kitchi Schist is a gray-green to brown, fragmental sericite schist, which in places resembles conglomerate. It probably formed from shallow water deposited volcanic ash and fragments. The unit occurs in a broad east-west trending band located south of Marquette (Van Hise and Bayley, 1897, p. 130).

u-- Ultramafic Rocks. This unit consists mainly of serpentinized peridotite. Exposures are generally dark green to reddish brown, massive except for blocky jointing, and locally cut by carbonate veins. At the Ropes Gold Mine northwest of Ishpeming, peridotite flanks the main ore body, and has been prospected for its own economic potential as verde antique. At Presque Isle, north of

Marquette, the Archean age of the intrusive body is in doubt, and it may be as young as Early Keweenawan. (Broderick, 1945, pp. 115-128; Gair and Thaden, 1968, pp. 56-57.)

db-- Diabase. This is a medium-grained, dark green, metamorphosed mafic rock rich in chlorite which occurs as dikes in the area east of Marquette. (Gair and Thaden, 1968, pp. 51-52.)

gb-- Gabbro. The gabbro found in the "Northern Complex" Area is a coarse-grained, mottled green, metamorphosed igneous rock, which occurs as small intrusive bodies. (Gair and Thaden, 1968, pp. 51-53.)

h-- Hornblende, Schist and Amphibolite. These coarsely crystalline, foliated rocks, in which amphibole and feldspar are the dominant minerals, are exposed in several areas in the Huron Mountains and in the central portion of the Study Area.

di-- Diorite. Diorite is a dark gray, coarse-grained, plutonic igneous rock composed mainly of feldspar with little or no quartz. A small body of this rock occurs on the Marquette-Baraga County line.

gd-- Granodiorite. Granodiorite is similar to granite except for mineralogical differences (mainly the type of feldspar present). An elongate area of this rock type is present in the "Northern Complex".

sy-- Syenite. Syenite is a dark red, massive to foliated plutonic igneous rock consisting principally of potash feldspar, hornblende, and little quartz. Small areas underlain by this rock type exist northwest of Marquette. (Gair and Thaden, 1968, p. 54.)

gn-- Granitic to Dioritic Gneiss. Granitic gneisses underlie a large portion of the Study Area and are especially abundant in the Northern and Southern Complexes of the Marquette Range. These plutonic rocks are foliated, generally pinkish rock with a composition generally ranging from tonalite to granodiorite with small amounts of monzonite and granite. There are, in addition, included

layers up to several feet thick of amphibolite and biotite-rich ronalite. Remnants of Mona-like schist found in the gneiss indicate its possible intrusive origin. The thickness of the gneissic unit is unknown. (Gair and Thaden, 1968, pp. 18-27.)

gr-- Granite. Large bodies of granite are mapped in the Huron Mountains and the central portion of the "Northern Complex".

b. Middle Precambrian (Huronian)

ce-- Enchanted Lake Formation. This formation consists of metamorphosed conglomerate, graywacke, arkose, sericitic slate and quartzite. It is discontinuous and lenticular, with a maximum thickness of 500'. (Gair and Thaden, 1968, p. 27.)

gm-- Mesnard Quartzite. The Mesnard is a hard, thick, massive, vitreous quartzite, generally light gray to pink, with thin interbeds of gray slate and conglomerate. The quartzite generally contains more than 90% quartz, is strongly jointed, ranges from 200-500' thick, and is thought to be correlative with the Sturgeon Quartzite of Dickinson County. (Gair and Thaden, 1968. pp. 34-37.)

dk-- Kona Dolomite. The Kona consists mainly of tan, pinkish or gray dolomite and interlaminated chert-dolomite, red quartzite, and, in the lower part of the formation, maroon, gray, and green sericitic slate. The dolomite is fine to medium grained, generally massive, and may be up to 1,200' thick. Laminated structures apparently formed by Precambrain algae are an indication of the shallow water origin of the dolomite. The Kona Dolomite is considered to be correlative with the Randville Dolomite of Dickinson and Iron Counties. (Gair and Thaden, 1968, pp. 37-45.)

sw-- Wewe Slate. In addition to slate, this formation contains sericitic quartzite and meta-conglomerate. Where fresh the slate is gray to greenish, and it weathers to brown or gray. It is massive to laminated, and is probably up to 900' thick in the synclinal structure south of Marquette. (Gair and Thaden, 1968, pp. 45-46.)

qa-- <u>Ajibik Quartzite</u>. The Ajibik Quartzite consists mainly of massive quartzite with minor amounts of thin bedded quartzite, slate, and conglomerate. In most places, the Ajibik is lithologically indistinguishable from the Mesnard Quartzite. One of the few visual differences is the presence of small yellowish or reddish brown iron oxide stains, which are rare in the Mesnard. The formation is approximately 650' thick, and is considered to be an equivalent of the Palms Quartzite of the Gogebic area and the lower part of the Felch Formation in Dickinson County. (Gair and Thaden, 1968, pp. 47-48.)

ss-- <u>Siamo Slate</u>. The Siamo Slate is mainly laminated to massive, dark argillaceous slate with minor interbeds of dark coarse-grained quartz-rich rocks. The formation is tightly folded in areas of outcrop near Marquette, and estimates of its thickness vary from 600-1,250'. (Gair and Thaden, 1968, pp. 48-49.)

in-- <u>Negaunee Iron Formation</u>. The Negaunee is a hard, mostly cherty, silicate iron formation with upper ore horizons of banded cherty or jaspery iron oxides (magnetite and hematite). It lies southwest of Marquette in an east-west trending synclinal trough, and may be up to 2,000' thick. Ore production from the Negaunee, the principal source of iron ore in the Marquette Range, has been continuous for more than 100 years, with the earlier production coming from the high grade ore, and the more recent production from lower grade ore which requires concentration. (Meshref and Hinze, 1970, p. 7; Cannon and Klasner, 1972, p. B7.)

qg-- <u>Goodrich Quartzite</u>. The Goodrich Quartzite is a relatively clean, dense, quartzose rock with discontinuous (but in some places thick--up to 300') interbeds of conglomerate and minor graywacke. The Goodrich is thought to unconformably overlie the Negaunee Iron Formation, and in the conglomeratic zone which separates them, iron minerals have been concentrated in sufficient quantity to produce low grade ore. (Cannon and Klasner, 1972, p. B19.)

sm-- <u>Michigamme Slate</u>. The Michigamme Slate is composed of units of interbedded slate and metagraywacke which crop out in a synclinal trough west of Ishpeming. (James, 1958, p. 37.)

ig-- <u>Greenwood Iron Formation</u>. The Greenwood is a hard, cherty silicate iron formation. It is a relatively thin unit which has been mapped in contact with the Michigamme slate approximately 10 miles west of Ishpeming, and may possibly be correlative with the Bijiki Iron Formation. (James, 1958, p. 36; Cannon and Klasner, 1972, p. B5.)

pc-- <u>Clarksburg Mafic Pyroclastics</u>. These are a group of metamorphosed mafic pyroclastic rocks (ejected volcanic ash fragments) with interbedded meta-argillite and iron formation. (Cannon and Klasner, 1972, p. B5.)

ib-- <u>Bijikki Iron Formation</u>. The Bijiki is mostly hard, cherty, silicate iron formation which, although of lesser importance than the Negaunee, has yielded quantities of high grade limonitic ore. (Cannon and Klasner, 1972, pp. B5 and B7.)

gkm-- <u>Michigamme Graywacke</u>. The Michigamme Graywacke is part of a widespread formation of gray slate and dark gray, massive, fine to medium grained metagraywacke which is probably on the order of 5,000' thick. This rock is the result of metamorphism of shaly sedments and volcanic debris. Several iron-rich beds are present in the formation. (Gair and Weir, 1956, p. 59; Cannon and Klasner, 1972, p. B5; Meshref and Hinze, 1970, p. 7.)

o <u>Iron River-Crystal Falls-Menominee Area</u>

a. Lower Precambrian (Archean)

gq-- <u>Quinnesec Greenstone</u>. The term Quinnesec Greenstone is applied to metavolcanic greenstones, amphibolites, and schists that form a belt in the southernmost part of Dickinson County. (James, 1958, p. 33.)

ake-- <u>East Branch Arkose</u>. The East Branch Arkose consists of poorly sorted, coarse grained arkose, arkosic conglomerate, and interbedded metamorphosed basalt and basic tuffs. In some areas, the arkosic beds appear gneissic, and the conglomerate pebbles are deformed and elongated. The formation is believed to be at least 1,000' thick. (James, 1958, p. 31.)

hs-- <u>Metasediments of Solberg Schist and Six Mile Lake Amphibolite</u>. These are principally biotite-hornblende schist, thin-bedded metachert and magnetic rock (iron formation), massive, gray quartz-mica schist, micaceous quartzite, and massive dark amphibolite. Most of the rocks appear to be metamorphosed sediments, with the exception of amphibolite, which is basaltic in composition and may represent altered volcanic flows and tuffs. The Solberg Schist unit, including a 100' thick section of iron formation, reaches a thickness of about 3,000', and the Six Mile Lake Amphibolite probably reaches a thickness of greater than 3,000'. (James, 1958, p. 32.)

gn-- <u>Granitic to Dioritic Gneiss</u>. Most of this unit, which is mapped in the Felch area, is reddish, porphyritic granitic gneiss, with sparse inclusions of schist and quartzite. There are also dark, medium-grained dioritic gneisses, and other light-colored gneiss. The rocks are generally well foliated, with layers trending east-west. The thickness of this unit is unknown. (James, 1958, pp. 31-33.)

gr-- <u>Granite</u>. Gneissic granite occurs in portions of the Study Area, and is probably younger than the metasediments of the East Branch, Solberg and Six Mile Lake Formations.

b. Middle Precambrian (Huronian)

cf-- <u>Fern Creek Formation</u>. This is a sequence of coarse-grained, clastic sedimentary beds which rest directly on granitic gneiss in southern Dickinson County. The formation occurs in isolated patches and includes some tillite (lithified glacial till). (James, <u>et al</u>., 1961, p. 31.)

qs-- <u>Sturgeon Quartzite</u>. This massive vitreous quartzite is lithologically and stratigraphically almost identical to the Mesnard Quartzite of the Marquette Range. Although variable, the thickness of this formation is nearly 2,000' in southern Dickinson County. (James, <u>et al</u>., 1961, pp. 31-33.)

dr-- <u>Randville Dolomite</u>. This locally metamorphosed formation of dolomite and slate is considered to

be correlative to the Kona Dolomite of the Marquette Range, and is up to 1,600' thick. (James, et al., 1961, pp. 33-36.)

qt-- Felch Formation. The Felch Formation is a heterogeneous group of rocks that includes mostly quartz-mica schist and quartzite, with magnetite-bearing quartzite and schists, and magnetic rocks. The Felch Formation is separated from the underlying Randville by an unconformity, and varies in thickness from 5 to several hundred feet. (James, et al., 1961, pp. 36-39.)

iv-- Vulcan Iron Formation. The economically important Vulcan Iron Formation consists mainly of gray-banded, oolitic, metachert and hematite, and varies in thickness from approximately 250' near Felch to almost 600' in southern Dickinson County. (James, et al., 1961, pp. 39-46.)

qg-- Goodrich Quartzite. The dense, deep red, ferruginous, cherty Goodrich Quartzite, which reaches a thickness of about 500' near Michigamme Mountain, is apparently correlative with the Goodrich of the Marquette Range. (Gair and Weir, 1956, pp 35-40.)

gh-- Hemlock Greenstone. The Hemlock consists of a thick series of altered basic volcanic flow rocks, tuffs and agglomerates, which now consist of massive to schistose and slaty greenstone. Narrow belts of slate and some graywacke have also been found. The formation completely surrounds an ellipsoidal gneissic intrusive body ("dome") near Amasa, termed the "Amasa Oval". The thickness of the Hemlock Greenstone is thought to be greater than 2,300'. (Gair and Weir, 1956, pp. 46-48.)

fh-- Hemlock Felsic Volcanics. The Hemlock Felsic volcanics consist of small exposures of well-bedded grayish-green to reddish rhyolitic tuff or felsite. (James, et al., 1961, pp. 46-48.)

gkm-- Michigamme Graywacke. Rock types within the Michigamme Graywacke are characterized by a range of metamorphic grade. A large part of the formation consists of moderately to intensely metamorphosed massive graywacke granulite and gray lustrous garnet-mica schists. There are also less metamorphosed beds of red or gray graphitic slate,

friable sandy graywacke, and slaty iron-rich rocks. Estimates of thickness range from 5,000' to a possible maximum of 11,000'. (James, *et al.*, 1961, pp. 48-51.)

gba-- <u>Badwater Greenstone</u>. The Badwater Greenstone consists principally of chloritized baslatic flows, some of which show structures which indicate underwater deposition. Near Iron River, these massive fine grained, greenish rocks attain a maximum thickness of several miles. (James, 1958, p. 37; James, *et al.*, 1961, p. 53.)

sd-- <u>Dunn Creek Slates</u>. The Dunn Creek is a sequence of siltstones, graywacke, and slates which is exposed near Crystal Falls and is probably 400-800' thick. The upper units contain slaty sideritic iron formation and a black pyritic graphitic slate. (James, 1958, pp. 37-38.)

ir-- <u>Riverton Iron Formation</u>. The Riverton is the productive Iron Formation for the Iron River-Crystal Falls district, and consists mainly of 100-600' of interbedded chert and siderite. (James, 1958, p. 38.)

gkh-- <u>Hiawatha Graywacke</u>. Overlying the Riverton Iron Formation (Locally with minor unconformity) is the clastic Hiawatha Graywacke. It includes slate interbeds and a breccia unit, but is dominantly 50-400' of metamorphosed graywacke. (James, 1958, p. 38.)

sfs-- <u>Stambaugh and Fortune Lake Slates</u>. Included as one mapping unit are the Stambaugh Formation siderite-magnetite slates, and the slates with minor graywacke of the Fortune Lakes Slates. The total thickness of the two formations is at least 4,000'. (James, 1958, pp. 38-39.)

o <u>Widespread Areas of Uncertain Correlations</u>

Nineteen other Middle and Lower Precambrian rock units have been identified and mapped in the Study Area. Because these units have only limited exposure or because their relationship with other rocks is uncertain, they have not been correlated with other known formations. The units are listed under the column entitled "Correlation with other Precambrian units uncertain" in the Key to Map Interpretation (Figure 1).

These generally metamorphosed units include metavolcanic rocks such as mafic tuffs and thyolite; plutonic rocks such as granite and migmatite; metasedimentary rocks such as tillite, conglomerate, arkose, graywacke-slate, quartzite, dolomite, and siltstone; dike rocks (mainly diabase); and iron formation. There are also magnetic units, probably iron formations, which are under a thick glacial cover and have been mapped mainly on the basis of magnetic surveys of the Study Area.

db_2-- Diabase

stn-- Siltstone

ms-- Magnetic strata, mostly concealed by overburden

i_2-- Iron formation

s_2-- Slate

gk_2-- Graywacke

d_2-- Dolomite

q_2-- Quartzite

ak_2-- Arkose

c_2-- Conglomerate

tr-- Tillite

r-- Rhyolite

mtf_2-- Mafic tuff

mag_2-- Mafic agglomerate

mig-- Migmatite

i_1-- Iron formation

mtf_1-- Mafic tuff

g_1-- Basaltic greenstone

g_1/mtf_1-- Undifferentiated basaltic greenstone and mafic tuff

Paleozoic

o Cambrian

Єls-- undifferentiated. This unit includes white to yellow dolomitic and glauconitic sandstones, locally quartzitic, which have not been assigned to a specific formation, but which can be placed in the Cambrian Period by relative age determinations or stratigraphic position.

Єj-- Jacobsville Sandstone. The Jacobsville Sandstone is exposed in a broad arc along the entire northern boundary of the Study Area. It is a fine to medium-grained, red to white, quartz sandstone containing minor coarse sand and conglomerate lenses. The formation is probably up to 2,000' thick in some areas, but pinches out locally. (Hamblin, 1958, pp. 15-25.) It is assumed to be Cambrian in age, although some researchers (Thwaites, 1943; Oetking, 1951; Meshref and Hinze, 1970) believe it to be Upper Precambrian.

Єm-- Munising Formation. The Munising Formation is a thin (about 200' thick) and easily identified sequence of medium-grained, white to grayish-blue, cross-bedded sandstone containing some blue shale layers and a pebble conglomerate at the base. It occurs in the eastern part of the Study Area. (Hamblin, 1958, pp. 71-109.)

o Ordovician

OЄsd-- undifferentiated. This map unit includes sandstones and dolomites which have not been assigned to a specific formation but are probably in the Cambrian to Ordovician age range.

Oat-- Au Train Formation. The Au Train is a resistant, brown to green dolomitic sandstone which is present throughout relatively extensive areas in the eastern part of the Study Area. Lenses of dolomite and sandstone are scattered throughout the 300' thick formation, and concentrations of glauconitic sands occur near the base. (Hamblin, 2958, pp. 115-120.)

Obr-- Black River Formation. The Black River Formation is composed of gray to bluish-gray to pink, fine grained to conglomeratic, well bedded, argillaceous limestone, and is located along the extreme eastern margin of the Study Area. (Hussey, 1952, p. 17.)

Structure

The Study Area is part of an ancient and geologically stable portion of the earth's crust known as the Canadian Shield. Geologic structures in the area were formed hundreds of millions of years ago during Precambrian and early Paleozoic time, and the region is presently tectonically quiescent.

Two regional structural features which have dimensions of hundreds of miles exist northwest and southeast of the Study Area. The Lake Superior basin is a northeast-trending synclinal trough formed where the rocks northwest of the Keweenaw fault dip gently toward the axis of this fold. Along the southeast edge of the Study Area, the Paleozoic rocks dip gently toward the Michigan basin, a dish-shaped feature with its center about 200 miles to the southeast.

The major fault in the region is the Keweenaw fault, a northwest-dipping reverse, or thrust fault that lies outside the Study Area to the northwest. This northeast-trending fault traverses the entire length of the Keweenaw peninsula and continues on a westerly trend across Wisconsin. On the Keweenaw peninsula, it separates Cambrian Jacobsville sandstone on the southeast from Precambrian rock on the northwest, and may have a total offset of as much as 3 miles, with the northwest side up. Because of this movement, the generally steeply northwest-dipping strata along the southeast side of the fault have been bent upward along the fault by drag-folding so that they dip to the southeast in some areas. Numerous smaller faults which moved during Paleozoic time have resulted in lateral offsets of the Keweenaw fault, and other, generally east/west-trending, faults cross portions of the area (see Bedrock Geologic Data Map). These east/west-trending faults have been located primarily on the basis of geophysical data, and appear to have resulted from tension produced by regional subsidence during the Paleozoic Era. There is no evidence for post-Paleozoic faulting anywhere in the Study Area.

In addition to the regional folds which border the Study Area, several smaller synclines and anticlines with dimensions of hundreds of feet to tens of miles exist within the area. These general east/west-trending zones of tightly

folded rock are of economic significance because iron formation crops out along the margins of the folds (see Mineral Extraction Data narrative). The largest and most important of these folds is a gently westward-plunging syncline 3 to 6 miles wide which extends 35 miles westward from the vicinity of Marquette. This major fold, along which the strata generally dip at 30° to 70° toward the axis, lies between and separates the two major granitic gneiss areas of the Upper Peninsula. Other major folds in the Study Area exist in the vicinity of Felch, Iron Mountain, and Iron River (see Bedrock Geologic Data Map).

Structures known as "gneiss domes", which consist of a central core of gneiss protruding up through the surrounding metasedimentary and metavolcanic rock, are also present in the Study Area. They have dimensions of a few miles and are of importance because iron formations are exposed around their margins.

RELATIONSHIP TO OTHER DATA

The distribution and character of mineral deposits are governed by bedrock geologic conditions, or by surficial geologic conditions in the case of sand and gravel deposits, placer gold, etc. The concentration of valuable minerals in specific locations within the earth's crust is the result of certain types of geologic processes, such as the intrusion of igneous rocks, unique sedimentological conditions, regional metamorphism, etc. Consequently, a definite relationship exists between various types of minerals and the host rock (or environment) in which they are likely to be found. For example, in the Study Area, copper, molybdenum, lead, zinc, gold and silver deposits are generally associated with greenstone belts, while the iron formations occur within the Middle Precambrian sedimentary rocks.

In many nonglaciated regions, soils are formed in place as a result of the weathering and decomposition of the underlying bedrock. In these areas, distinctive residual soils may be the key to mapping the underlying bedrock. These relationships do not prevail in the Study Area, since the bedrock formations are generally covered by up to 300 feet of glacial materials. Only in areas of very thin glacial cover does the bedrock in the Study Area affect soil types, and then only to a minor degree. The limited exposures of consolidated rock have little or no soil, which is primarily the result of the slow weathering and breakup of the rocks. The presence of glacial striations, or "scratches", on the surface of some of the in-place crystalline rocks, indicates that very little rock has been removed by weathering during the last 10,000 years, and this explains the lack of soil.

Bedrock geology in the Study Area is, to a small degree, related to topography. For example, topographically steep or rugged areas such as knobs, ridges, etc., are mainly underlain by hard rock with little or no surficial cover.

Bedrock geology has limited effects on vegetation and land use. Rough, knobby areas tend to have thin or no glacial deposits, and, consequently, little or no soil formation that would support a dense growth of vegetation. These areas of knobby terrain and thin surficial cover tend to be areas of mining activities and related mineral production. The lake plains and hilly glacial moraine areas, where surficial cover is thicker, are locally cultivated and used for crops and pasture.

Bedrock geology is related to the occurrenc of ground water. The hard, crystalline Precambrian rocks are extremely poor aquifers, and almost total dependence is placed on glacial deposits for supplying ground water in areas where bedrock is of this type. If glacial deposits are thin over these crystalline rock areas, only small yields of water can be expected. The younger Precambrian and Paleozoic sedimentary rocks on the northern and eastern borders of the Study Area generally yield considerably more water to wells, and are important sources of ground water in some areas.

VALIDITY

General Procedures and Data Sources

The Bedrock Geologic Data Map represents an unchecked compilation of all pertinent existing bedrock geologic mapping available for the Study Area. As is the case with most traditional geologic mapping, surficial deposits have been largely ignored, and the map shows the types of rock present at depth. Little information is presented that pertains to the condition of the rock at or near the surface, or to the presence or absence of soil deposits in a given area.

Geologic maps providing complete coverage of the Study Area were available at scale ranging from 1:24,000 to 1:500,000. Since these varying scales were used in the compilation, the information presented is more accurate in some portions of the Study Area than it is in others, although an attempt was made to attain a uniform level of detail. The Index to Available Geologic Mapping in the Study Area, Figure 2, shows the locations of maps used in the compilation of the Bedrock Geologic Data Map. The geology of the rocks of Precambrian age (which encompasses the majority of the Study Area) was obtained from Willard A. Bodwell's 1972 map, "Precambrian Geology of Upper Peninsula, Michigan", which is itself a compilation of all mapping that was available for the area at that time. In some areas, contacts were modified to conform with those shown on a revised copy of Bodwell's map prepared and made avaiable by Kalliokowski in September 1973. Geologic data for Paleozoic rock formations were obtained from State and Federal maps varying in detail and scale. At present, little work has been done in detail on the Paleozoic bedrock of the Study Area. A general indication of the status of mapping throughout the Study Area is presented on Figure 3 of the Mineral Extraction Data narrative.

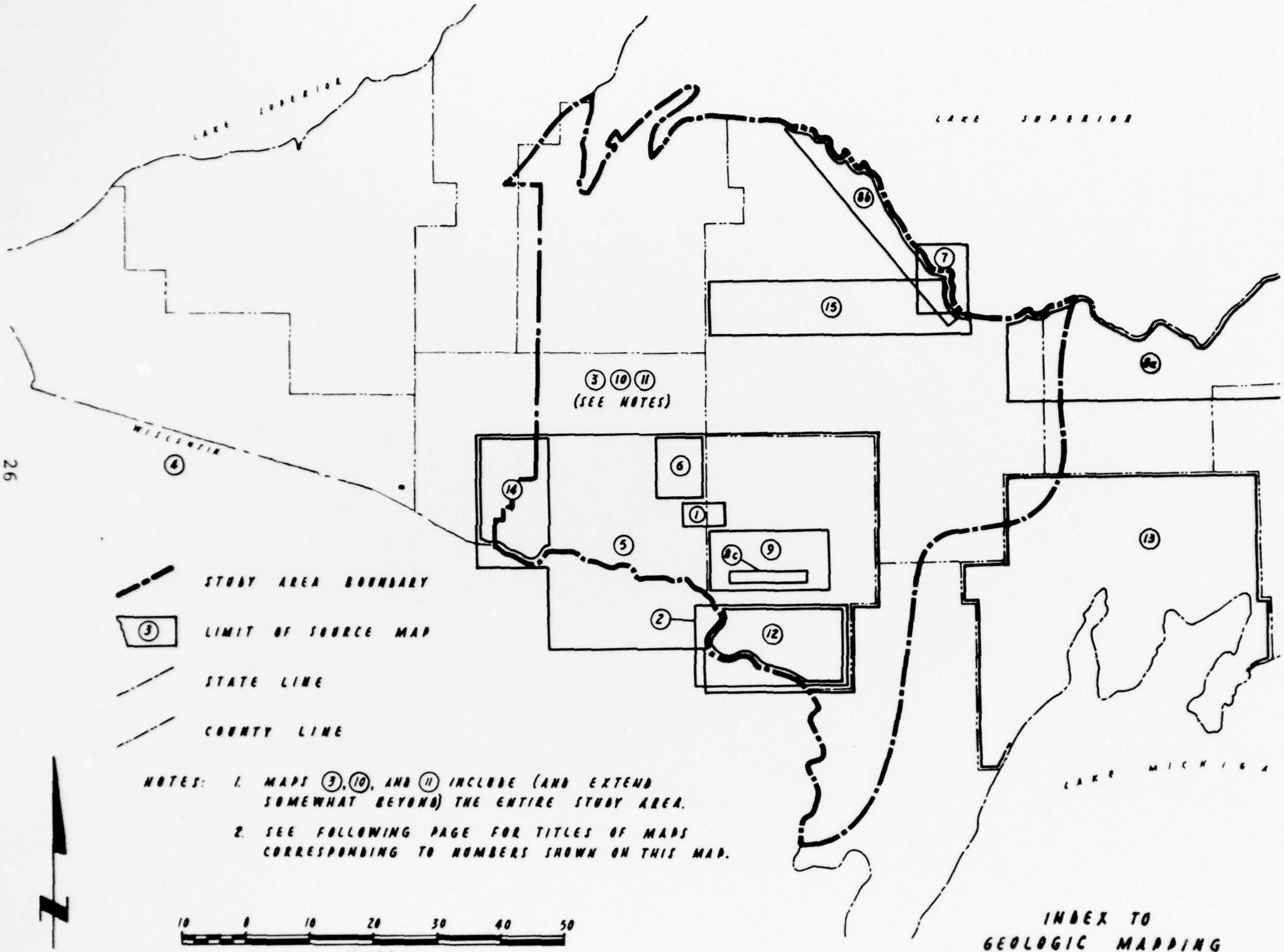
The intended use of this map is to provide a basis for determination of the rock type present at depth within any general section of the Study Area. Rock quality is not shown.

Data Reliability/Specific Procedures/Limitations

The Bedrock Geologic Data Map provides information on the distribution of rock types at depth below soil and glacial cover. Because the data were compiled from pre-existing maps which ranged in scale from 1:24,000 to 1:500,000, and

in publication date from 1911 to 1973, the accuracy of mapping varies. Additionally, some adjustments had to be made where maps of differing scales adjoin. Contacts were also adjusted somewhat to conform with the topography shown on the base map where it was obvious that this was necessary.

Since glacial deposits blanket most of the Study Area and little detailed field work has been done in large areas of Upper Michigan, locations of some formational contacts and geological features should be considered as reliable estimates rather than precise determinations. In particular, there are large areas where little or no information on bedrock conditions is available north of the Marquette Range (see Bedrock Geologic Data Map), and many Keweenawan dikes in the central portions of the Study Area are only approximately located.



INDEX TO
GEOLOGIC MAPPING
IN THE STUDY AREA

TITLES OF MAPS SHOWN ON FIGURE 2

1. Bayley, R. W., 1959. Geology of the Lake Mary Quadrangle, Iron County, Michigan, USGS Bulletin 1977, p. 64.

2. Bayley, R. W., Dutton, C. E., and Lamey, C. S., 1966. Geology of the Menominee iron-bearing district, Dickinson County, Michigan, and Florence and Marinette Counties, Wisconsin. USGS Prof. Paper 513, Plates 1, 2, and 3.

3. Bodwell, W. A., 1972. Precambrian geology of Upper Peninsula, Michigan, a compilation, part of Master's thesis, Geol. Map Series, Map 2, Michigan Technological University Press.

4. Dutton, C. E., and Bradley, R. E., 1970. Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin: USGS Misc. Geol. Inv. Map I-631, Sheets 3 and 4

5. Dutton, C. E., and Linebaugh, R. E., 1967. Map showing Precambrian Geology of the Menominee Iron-bearing District and Vicinity, Michigan and Wisconsin, USGS Misc. Geol. Investigations, Map I-466.

6. Gair, J. E., and Thaden, R. E., 1968. Geology of the Marquette and Sands Quadrangles, Marquette County, Michigan; USGS Prof. Paper 397, Plate 1.

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8. Hamblin, W. K., 1958. The Cambrian sandstones of northern Michigan: Michigan Department of Conservation, Geol. Survey Division Pub. 51, 146 pp. (8a is Plate 2 of this report; 8b is Plate 3, and 8c is Plate 4.)

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13. Michigan Geological Society, 1950. The Ordovician rocks of the Escanaba Stonington area, annual field trip, June 1950, led by R. C. Hussey. Map: West half Delta County.

14. and 15. Van Hise, C. R., and Leith, C. K., 1911. The geology of the Lake Superior region, USGS Monograph Vol. 52. (9 is Plate 24 of this report, 10 is Plate 17.)

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